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CRITICAL ANALYSIS OF BUILDING WITH VERTICAL IRREGULARITIES AS PER IS1893 Part-1:2002

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ABSTRACT

Earthquake forces are not only responsible for the loss of economy property and material but possess a huge threat to lives of people as well. In recent past years, serious damages and causalities due to these disastrous forces have been visualized and various lessons have been learned mainly by the designing and construction authorities. In the present study, the effect of vertical irregularity in a building is studied with the help of different analysis methods. Linear elastic analysis, nonlinear static pushover analysis, and linear dynamic response spectrum analysis are applied on structures with one or more vertical irregularity incorporated in it so as to study the individual as well as the combined effect of these irregularities. The incorporated irregularities are as per IS1893 Part-1:2002. The results obtained are discussed under the following headings such as displacement values, mode shapes, modal time period, modal mass participation factor, base shear performance point capacity of structure and hinge formation pattern are compared and studied for various irregularities in structure with and without infill walls. All comparisons are represented graphically and also in tabulated form in terms of percentage variation wherever required.

KEYWORDS: Vertical Irregularities, Performance Point, Capacity of Structure, Modal Mass Participation, Modal Time Period, Mode Shapes, Base Shear & Hinge Formation

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Original Article

INTRODUCTION

With all past experiences of the devastation caused by earthquake hitting, the damages and causalities of the irregular structure are much accountable than that for a regular structure. The constructions of irregular structures are inevitable with increasing architectural demands and hence the structural designers' need to completely understand the complexity of the behavior of these structures under strong ground shakings. Incorporating high engineering effort can reduce the threat upon irregular structures. Also under actual conditions, various irregularities in a building combine to initiate the disastrous effect. Understanding the effect on the building when these irregularities are combined is also of great importance.

Types of Irregularities in a Building

Basically, there are two types of irregularities in a building i.e. plan irregularity and vertical irregularity (IS1893 part-1, 2002). Plan irregularity includes torsion irregularity, re-entrant corners, diaphragm discontinuity, out of plan offsets and non-parallel systems in a building. Vertical irregularity in a building can be classified as

- **Stiffness Irregularity – Soft story** : One in which the lateral stiffness is less than 70 percent of that in the story above or less than 80 percent of the average lateral stiffness of the three story above .

- **Stiffness Irregularity - Extreme Soft Story :** One in which the lateral stiffness is less than 60 percent of that in the story above or less than 70 percent of the average stiffness of the three story above.
- **Mass Irregularity** exists where the seismic weight of any story is more than 200 percent of that of its adjacent story. The irregularity need not be considered in case of roofs.
- **Vertical Geometric Irregularity:** Exists where the horizontal dimension of the lateral force resisting system in any story is more than 150 percent of that in its adjacent story.
- **In-Plane Discontinuity in Vertical Elements Resisting Lateral Force:** exists when an in-plane offset of the lateral force resisting elements is greater than the length of those elements.
- **Discontinuity in Capacity: Weak Story :** one in which the story lateral strength is less than 80 percent of that in the story above, where story lateral strength is the total strength of all seismic force resisting elements sharing the story shear in the considered direction.

All design against seismic loads must consider the dynamic nature of the load. However, for simple regular structures, analysis by equivalent linear static methods is considered sufficient. Such analysis can work well for low to medium-rise buildings without significant discontinuities and where only the first mode in each direction is considered. Tall buildings (75m and above), where second and higher modes can be important, or buildings with torsional effects, are much less suitable for this method and require more complex methods to be used in these circumstances. In the present study linear static method, linear dynamic method and non-linear static pushover analysis (ATC40, 1996) is used to analyze the considered buildings.

PROBLEM FORMULATION

In the present study, a regular hypothetical building is taken as a reference and all irregularities are induced in them to study the effects. Models of the building are prepared with and without brick infills modelling in SAP2000(SAP2000, 2004). The lists of the models taken for study are

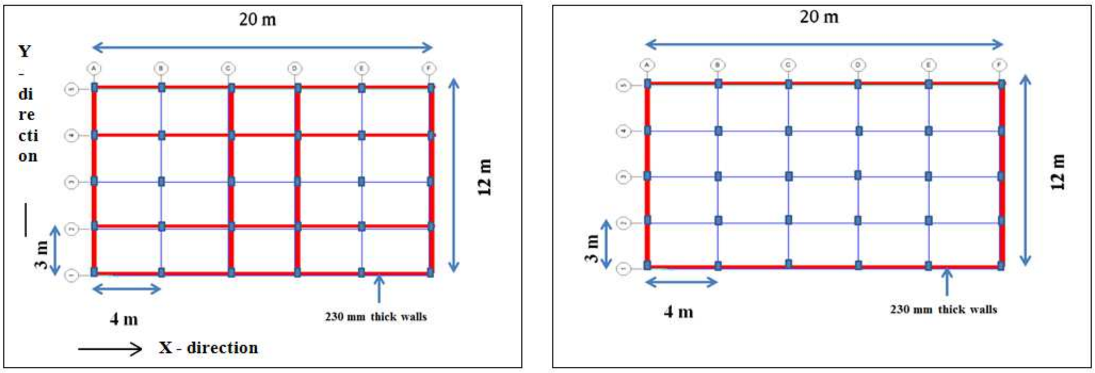
- Regular building
- Building with soft story effect at ground level
- Building with soft story effect at the intermediate level
- Building with setbacks
- Building with mass irregularity in plan
- Building with mass irregularity in elevation
- Building with the combined effect of soft story and setbacks
- Building with the combined effect of soft story at ground level setbacks and mass irregularity
- Building with the sloping ground

Total 18 models are taken for study. Typical specifications for all considered models are given in Table1. Plan of a regular building at typical floor and roof level is shown in figure 1. Elevation of the regular building is shown in figure 2.

230 mm thick walls are assumed on all highlighted beams at all typical floors. Parapet wall 230 mm thick and 1 m high is assumed at roof level as highlighted in the figure. Sizes of beams and columns are assumed so as to allow maximum of 1.5 % area of steel in beams and 2.5% area of steel in columns in all frames. Infill wall is modeled as equivalent strut as per guidelines of FEMA 306, and IS1905. Equivalent strut sizes come out to be 230mm x 510 mm in the x-direction and 230mm x 440 mm in y –direction.

Table 1: Specifications for the Models Considered

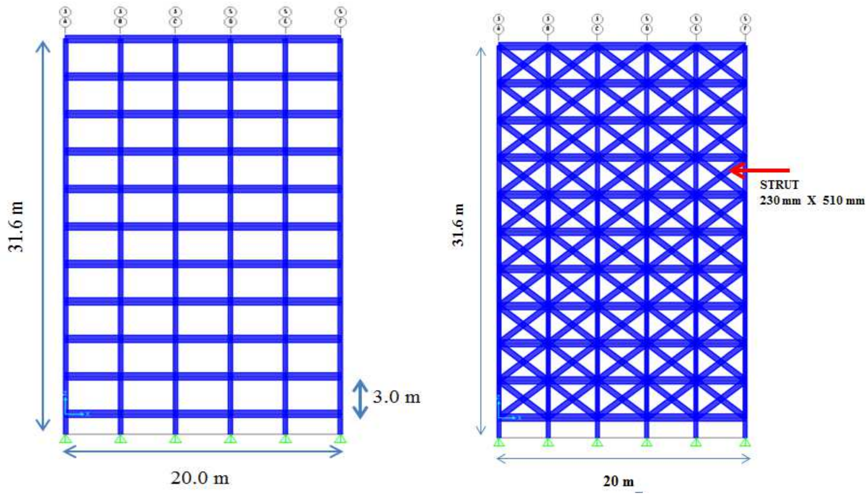
Type of the Building	Residential Building
Location of the Building	Delhi
Seismic Zone	Zone-4
No. of Storey	G+10
Floor height	3 m
Plan area	20m x12 m
Grade of concrete	M 30
Grade of steel	Fe 415
Beam size	300mm x 600mm
Column size	350mm x 600mm
Slab thickness	125 mm
Wall thickness	230 mm
Density of concrete	25 kN/m^3
Density of masonry	20 kN/m^3
Yield strength of steel	415 N/m^2
Zone factor	0.24
Type of soil	Medium



(a) **(b)**

Figure 1: Plan of Regular Building
(a) Typical Floor Level (b) Roof Level

Loads assumed for the analysis are given in Table 2. The seismic forces are considered as per IS1893 part-1. Accordingly, the time period for buildings with and without brick in fills will differ as shown in Table 3. Wind load on the building was calculated but the seismic force was governing and hence only seismic forces were taken into considerations. Load combinations for the analysis and design of buildings are as per IS1893 part-1.



(a) (b)

Figure 2: Elevation of Regular Building
(a) Without Infills (b) With Infills

Table 2: Loads Assumed

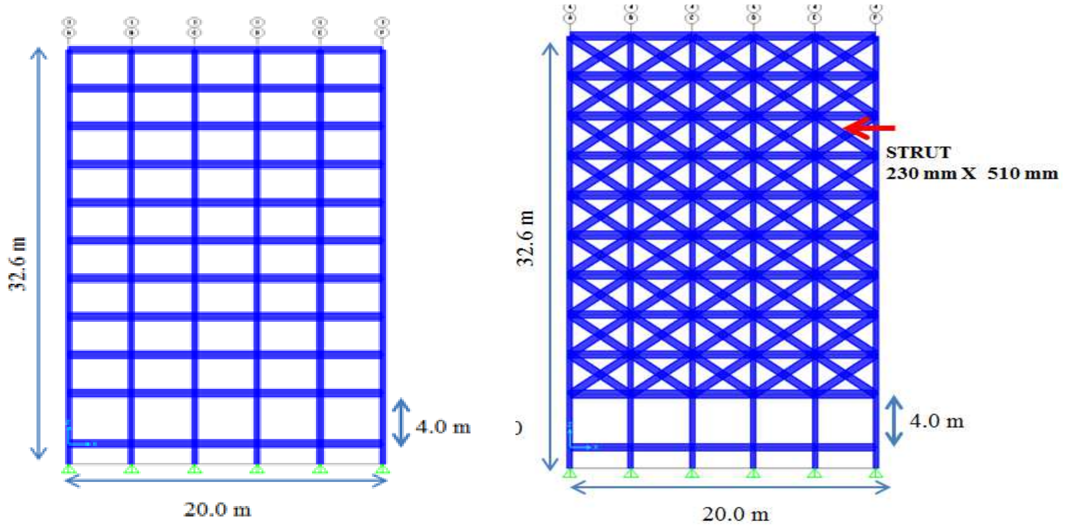
Load	Intensity
Floor finish – Dead load at typical floor	1 kN/m^2
Floor finish – Dead load at Roof level	2 kN/m^2
Live load at typical floor	2 kN/m^2
Live load at roof level	1.5 kN/m^2

Table 3: Time Period of the Regular Building as per IS1893 Part-1

Specification	Time Period
Time period of the building without infills $T = 0.075 \times h^{0.75}$	1.0 s
Time period of building with infills $T = 0.09h/\sqrt{d}$	0.635s in x-direction 0.82s in y-direction

The elevation of buildings with the soft ground story is shown in figure 3. Soft story is induced at ground level by increasing the height of the floor and removing wall load. Apart from the change in geometry, change in time period of the buildings is also observed as shown in Table 4. The elevation of buildings with soft intermediate story is shown in figure 4. Soft story is induced at fifth-floor level by increasing the height of the floor and removing wall load. Apart from the change in geometry, change in time period of the buildings is also observed. The elevation of buildings with the setbacks is shown in figure 5. The definition of setback in the building has been justified as per IS1893 part-1.

The elevation of buildings with mass irregularity in plan and elevation is shown in figure 6 and figure 7. To achieve mass irregularity, heavy load of 30 kN/m^2 is assigned at seven story level.

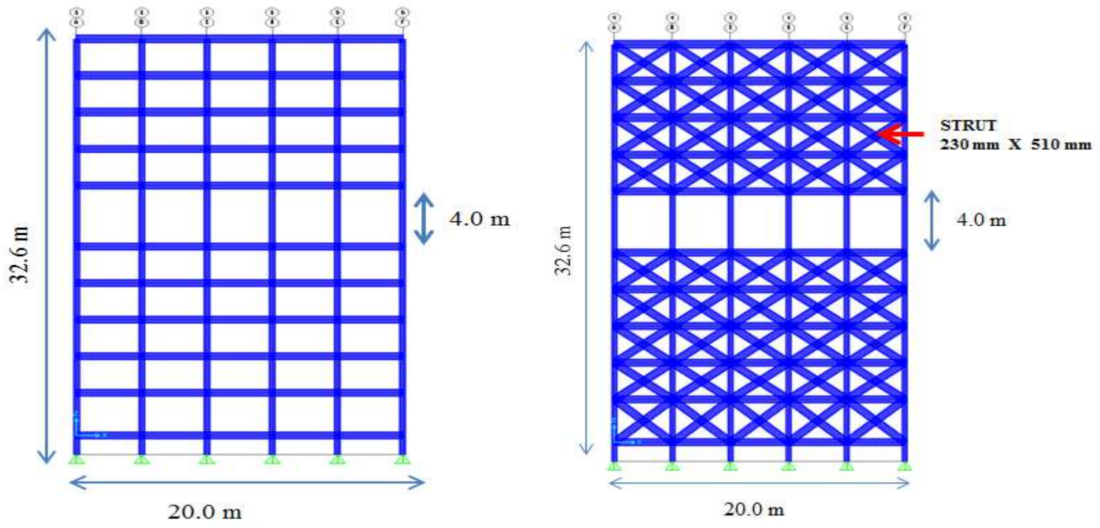


(a) **(b)**

Figure 3: Elevation of Building with Ground Soft Storey (a) Without Infills (b) With Infills

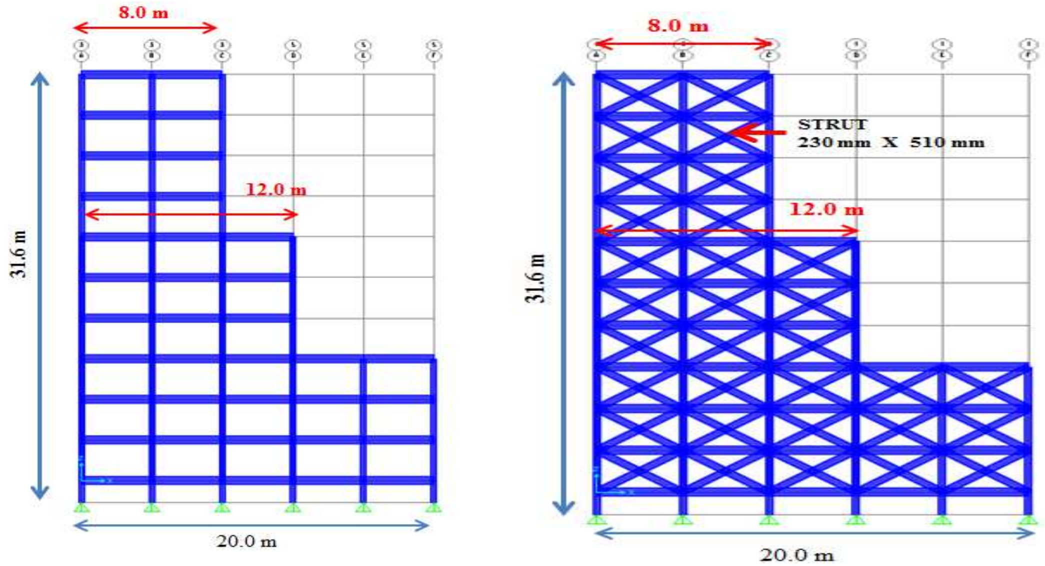
Table 4: Time Period of the Building with Ground Soft Storey

Specification	Time Period
Time period of the building without infills	1.023s
Time period of building with infills	0.66s in x-direction 0.85s in y-direction



(a) **(b)**

Figure 4: Elevation of Building with Intermediate Soft Storey a) Without Infills b) With Infills



(a) (b)

Figure 5: Elevation of Building with Setbacks
(a) Without Infills b) With Infills

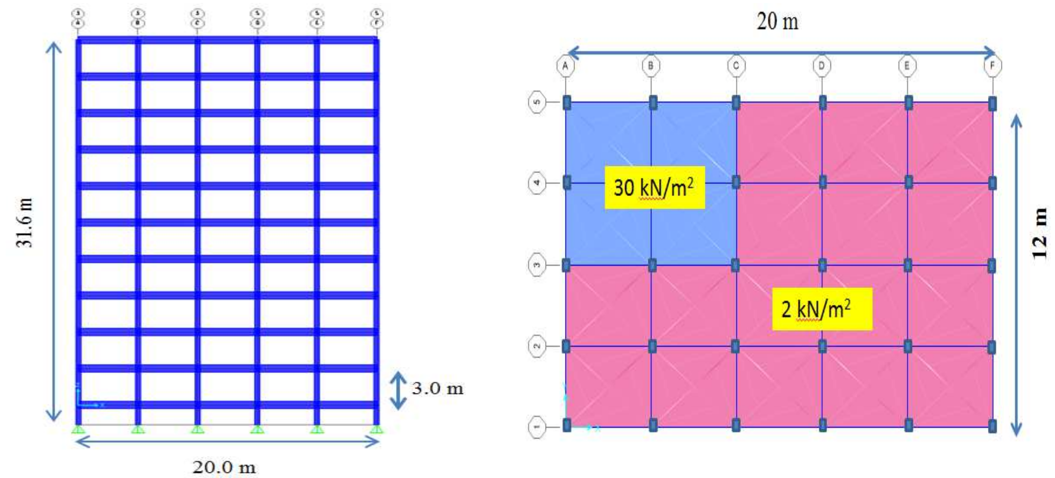


Figure 6: Inducing Mass Irregularity in Plan (Without Infills)

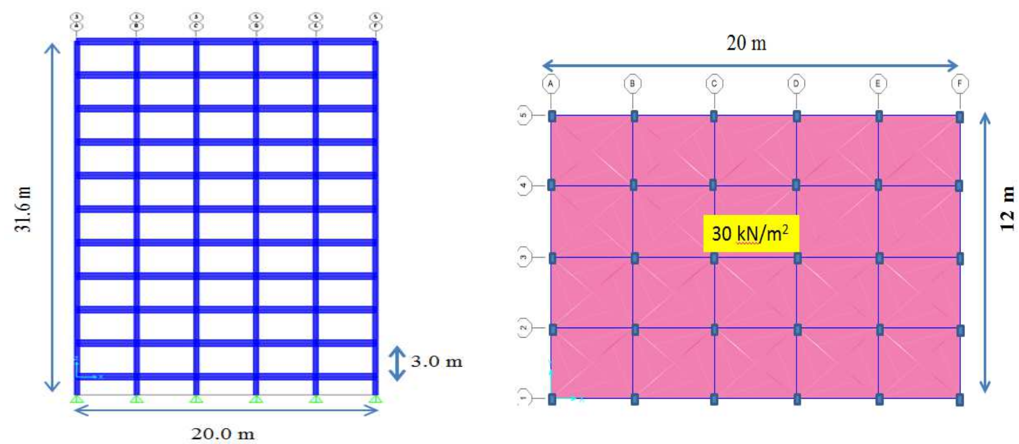
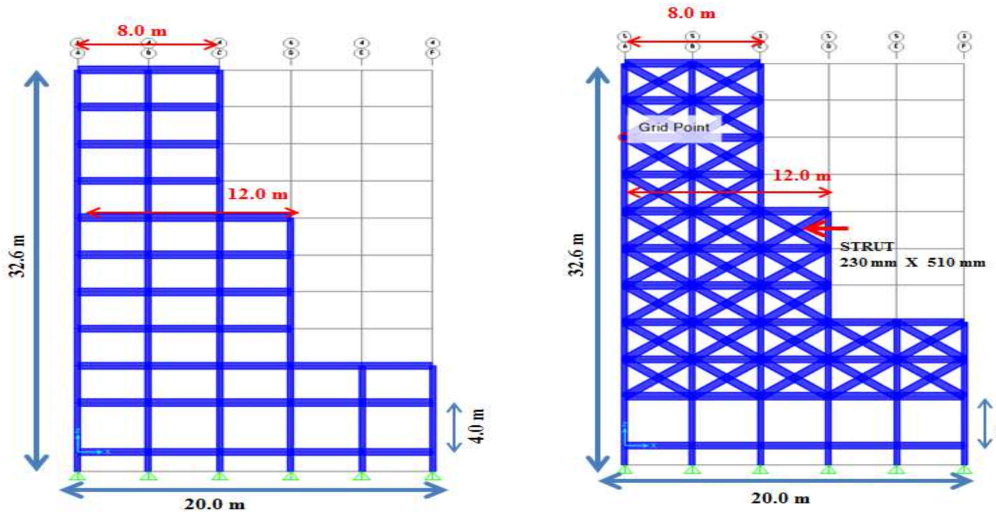


Figure 7: Inducing Mass Irregularity in Elevation (Without Infills)

The elevation of building with the combined effect of soft story and setbacks is shown in figure 8. Wall load has been removed from ground story and height of ground storey is increased to create soft story. The elevation of building with the combined effect of soft story, setback and mass irregularity is shown in figure 9. Heavy load of 30 kN/m^2 is assigned at nine story level.



(a) **(b)**

Figure 8: Building with Combined Effect of Soft Storey and Setbacks a) Without Infills b) With Infills

The elevation of building with sloping ground effect in the single story and at all floors is shown in figure 10. Gradual variation is applied in height of column form 0.75 m to 4.6 m. Tie beam is not provided at plinth level.

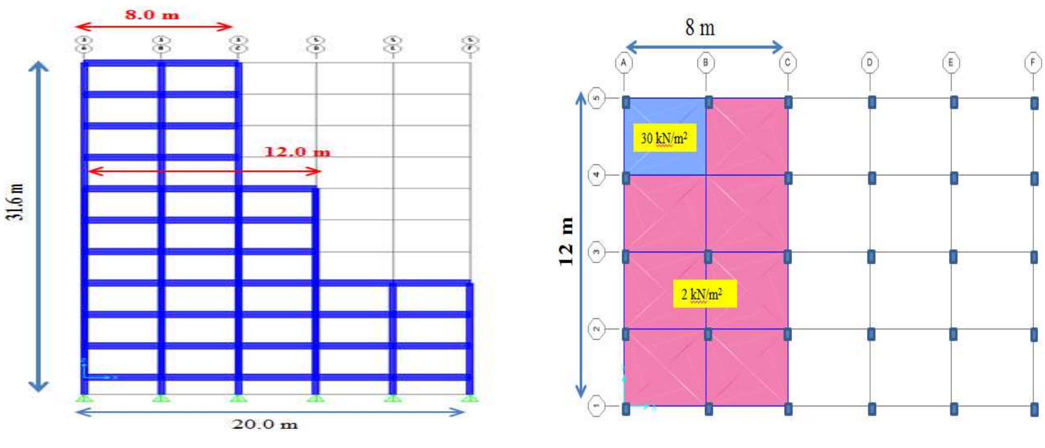


Figure 9: Building with Combined Effect of Soft Storey, Setback and Mass Irregularity (Without Infills)

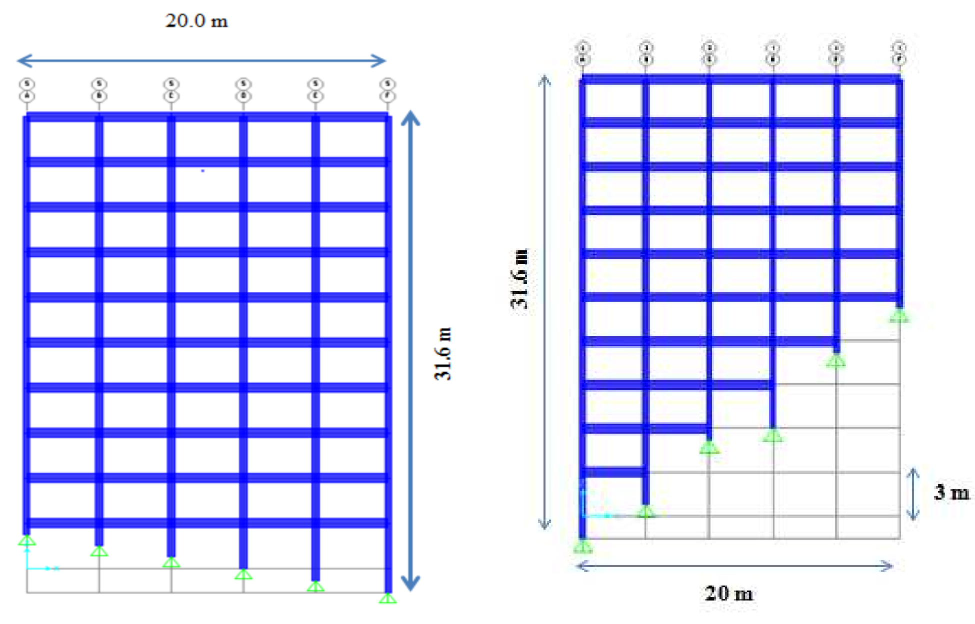


Figure 10: Building with Sloping Ground a) at Single Storey b) at Various Floors

RESULTS AND DISCUSSIONS

Analysis results are interpreted and discussed under the following headings

- Displacement values
- Comparison of building with infill walls effect and without infill wall effect between linear static method and linear dynamic method (response spectrum).
- Mode Shapes
- Modal time period
- Base shear values
- Performance points
- Capacity of structure
- Hinge formation pattern.
- Modal mass participation factors

Displacement Values

- **Effect of Infill Walls**

The effect of infill walls can be observed clearly, the displacement values of building without infills are about 40% higher than that of building with infills in thex-direction and 25% in the y-direction.

- **Linear Static v/s Linear Dynamic Analysis**

The displacement values obtained from the linear static analysis are higher than those obtained from the linear dynamic analysis for the regular building, building with ground and intermediate soft story and building with mass irregularity in plan and elevation, with the variation of about 20 %.

The displacement values obtained from linear dynamic analysis are higher than those obtained from the linear static analysis in buildings with setbacks, in the most corner frame continuing till G+ 4 level and in buildings on sloping ground, with the variation of about 60%.

Mode Shapes

It is observed that the building undergoes translation along with torsion, in the primary mode shapes for the following irregularities:

- Building with setbacks
- Building with mass irregularity in plan and elevation.
- Building with a combination of setbacks and soft storey.
- Building with a combination of setbacks, soft storey and mass irregularity in plan.
- Both cases of building on the sloping ground.

The effect of torsion is observed in the above buildings due to variation in center of mass and center of rigidity. The eccentricity generated due to variation in Center of mass and Center of the rigidity, reduces by about 50 %when infill are modeled. In building with mass irregularity in elevation, the eccentricity is observed only at the floor where mass is induced. In mass irregularity in plan, all stories shows variation in eccentricity. In building on sloping ground huge variation in eccentricity is observed at lower level.

Modal Time Period

About average of 30 % variation is observed in buildings considered, due to the effect of infill walls. The modal time period is 30 % more of building without infills than that of infills.

Performance Point

Presence of infill walls increases the capacity of building, thus the value of performance point is about 30 % higher than that obtained in building without infill walls. As the irregularity in structure increases, the performance point drops down. The percentage variation in base shear and performance point of the building is about 50%, thus still huge residual force remains.

Capacity of Structure

The capacity of structure drastically increases with the presence of infill walls and it accounts for up to 50 % in case of regular structure. The capacity of the regular building is approximately 30% higher than that of the irregular building. As two or more irregularities are induced, capacity further reduces. No such variation in capacities is observed between buildings with setbacks + soft story at ground level and buildings with setbacks + soft story at ground level + mass irregularity in the plan.

Hinge Formation Pattern

Hinge formation is not observed at floor where infill walls are modeled. Structural members of floors where infill walls are not modeled undergo hinge formation. Structural members of soft story level undergo hinge formation earlier than other regular floors. In building on sloping ground case-1, hinges are formed in the shortest column, generated due to the effect of sloping ground. In building on sloping ground case-2, no hinges are observed in columns. In buildings with setbacks and mass irregularity in plan and elevation, no such regular pattern is observed .

The hinge is formed both in beams and columns and raises from bottom to top level. In combined effect of irregularities, a prominent effect of the soft story is observed where hinge formation pattern is considered.

CONCLUSIONS

Effect of Infill Walls on Buildings

- Reduces displacement values and controls drift.
- Reduces the eccentricity generated due to variation in center of mass and center of rigidity, thus reducing the effects of torsion.
- Modal time period reduces considerably.
- Performance points and capacity of the building increases drastically.
- Restrict hinge formation in structural members.

Clearly, the effect of infill walls is of significance, as we do not generally consider infill walls in modeling, we are neglecting its effect and are being on more conservative side.

Methods of Analysis

- As linear dynamic analysis depicts more realistic conditions, it predicts the actual behavior of earthquake and its results are more considerable. The effect of linear dynamic analysis can be observed prominently in irregular geometrical structures. Thus it can be said that linear static analysis results are much on the conservative side and does not capture the actual effect.
- The capacity of building obtained from push over analysis is much higher than the base shear values obtained from equivalent linear static analysis method

Our code method being on much conservative side, we are not taking into account actual conditions of ground shaking.

Effect of Irregularities on Buildings

- Performance point and capacity of structure reduce as irregularities are induced, due to the reason that the building becomes more vulnerable with more irregularities.
- Setbacks and soft story in building shows more drastic effects where variation in capacities and hinge formation pattern is considered, whereas mass irregularity contributes less and shows negligible effects .

Moments and Forces at Soft Storey Level in Beams and Columns

Variation of moments in column and beams,

Moments in column = 2.4 times of that in the regular structure

Moments in beams = 1.58 times times of that in the regular structure

Justifying the codal provisions for columns but for the beams it is on much conservative side and factor can be reduced.

Sloping Ground Effect

When building on sloping ground is to be constructed, case -2 is the better option as the columns get tied at each level, which does not generate varying stiffness resulting in short column effect ,and beams tend to fail earlier than column, making the building safe against collapse.

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